A Benefit-Cost Analysis Model for Implementing Construction CALS

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ABSTRACT

The objective of this paper is to discuss why Construction CALS (C-CALS, in short) is needed for complex construction projects and to propose a benefit-cost analysis model for justifying the implementation of C-CALS from the viewpoint of economy. This paper identifies six different Cases of data standardization for the delivery process of construction projects. Furthermore, a detailed cost estimating of each case has been developed to guide the enterprise to implement an efficient and economic CALS-like system. In addition, a case is selected to demonstrate how the proposed model can be applied. With this model, owners can analyze the items of cost and benefit of implementing CALS, and then are able to decide whether an engineering facility is suitable for implementing CALS strategies.

Keywords: Construction Automation, CALS, Cost-Benefit Analysis, Information Technology

1 INTRODUCTION

The strategy of Continuous Acquisition and Life-Cycle Support (CALS) was first promoted by the U.S. Department of Defense (DoD) in 1985. By creating standards for products (weapons) and using information technologies to create a paperless environment, CALS facilitates the sharing of life-long data associated with weapons among the owners, producers, users, and maintenance people [1]. With the ideas of data being created once and used many times, the primary goal of CALS is to improve quality and efficiency, and to reduce cost, of defense weapons along their life cycle.

Due to the success of CALS in defense industry, many other industries have applied the CALS concept to improve the overall performance of their products in many countries since 1990. The construction industry is characterized as a fragmented production system, in which automation and information technologies are not highly utilized. Thus, the cost reduction and quality improvement of the construction industry has never been satisfied. The application of

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CALS to the construction industry can be a new opportunity for greatly improving the overall performance of the construction industry.

The objective of this paper is to discuss why Construction CALS (C-CALS, in short) is needed for complex construction projects and to propose a model for justifying the implementation of C-CALS from the viewpoint of economy. In the remaining sections of this paper, discussions on why C-CALS is needed for complex construction projects as well as an introduction to C-CALS and its implementation characteristics are first provided. Then, cost and benefit of implementing C-CALS are addressed. A model for Benefit-Cost Analysis when implementing C-CALS is proposed for determining which types of construction projects are appropriate to adopt the strategy of CALS. In addition, a case is selected to demonstrate how this model can be applied. With this model, owners can analyze the items of cost and benefit of implementing CALS, and then are able to decide whether an engineering facility is suitable for implementing CALS strategies.

2 CONSTRUCTION CALS

Large amount of engineering information, usually documented by paper-based format, is created along the delivery process and activities of a construction project. Paper-based documents are not as efficient as electronic documents for creating, storing, processing, and distributing information. In addition, the lack of standards for exchanging engineering information among related parties (e.g., owner, designer, contractor, constructor, government, etc.) often makes sharing and reuse of information very difficult during the life cycle of a construction project, leading to duplicated works, missing or error-prone works, and inefficient works.

The CALS strategy proposes a set of standards to enable and accelerate the integration and sharing of digital technical information for acquisition, design, manufacturing, and maintenance support of weapons [2]. By establishing exchange standards and building an electronic environment to facilitate sharing of technical information via computer networks, CALS is expected to shorten the delivery duration, reduce the cost in the life cycle, and improve the quality of weapons. Although CALS technologies were dominated by defense markets in the past, their relevance and applicability to a widening scope of business has been recognized worldwide [3]. Since 1990, many industries (other than defense industry) have been adopting CALS or CALS-like technologies for continuously improving the productivity and quality of their products along life-cycle processes. It is also possible for the construction industry to implement CALS, so efficient sharing, exchange, and reuse of engineering information in electronic format can be achieved throughout the life cycle of a construction project.

Two types of criteria may be considered to evaluate whether or not an industry is appropriate for adopting the CALS strategy [4]. The first one, called primary factors, is related to the inherent complexity of the industry. The primary factors considered here include: (1) complexity of describing products and their components, (2) complexity of specifying production process and required materials/equipment, and (3) complexity of coordinating resources and integrating activities at each stage of the life cycle. The second one, called secondary factors, is considered to be amplification factors to the primary factors. The secondary factors considered are: (1) if management of paper documents is essential, (2) if integration of distributed data is required, (3) if market is changing rapidly, (4) if products are characterized with low production quantity but various contents, and (5) if the life cycle of products is long. If an industry meets such criteria, then it is a potential industry for applying CALS. If an industry is highly complex in terms of the primary factors and answers "yes" to most of the questions raised by the secondary factors, the industry has great potential for applying CALS. Table 1 shows the result of evaluating the construction industry for application of CALS. As can be judged from the table, Construction Industry is an ideal area to apply CALS.

Table 1. Evaluation of Applying CALS to Construction Industry [4]

Factors Considered	rank/ y/n
1.Complexity of describing products and their components	high
2.Complexity of specifying production process or equipment	high
3.Complexity of coordinating resources and integrating activities	high
4.Management of paper documents is essential	yes
5.Integration of distributed data is required	yes
6.Market is changing rapidly	no
7.Products have low production quantity but various contents	yes
8.Life cycle of products is long	yes

Applying CALS to construction projects will enable the creation, storage, processing, and distribution of electronic engineering information generated among the planning, survey, design, estimation, procurement, construction, and operation and maintenance stages (as shown in Figure 1). It will allow efficient sharing and reuse of the information by responsible agencies and contractors, leading to improved quality and productivity of the project and reduced construction costs.

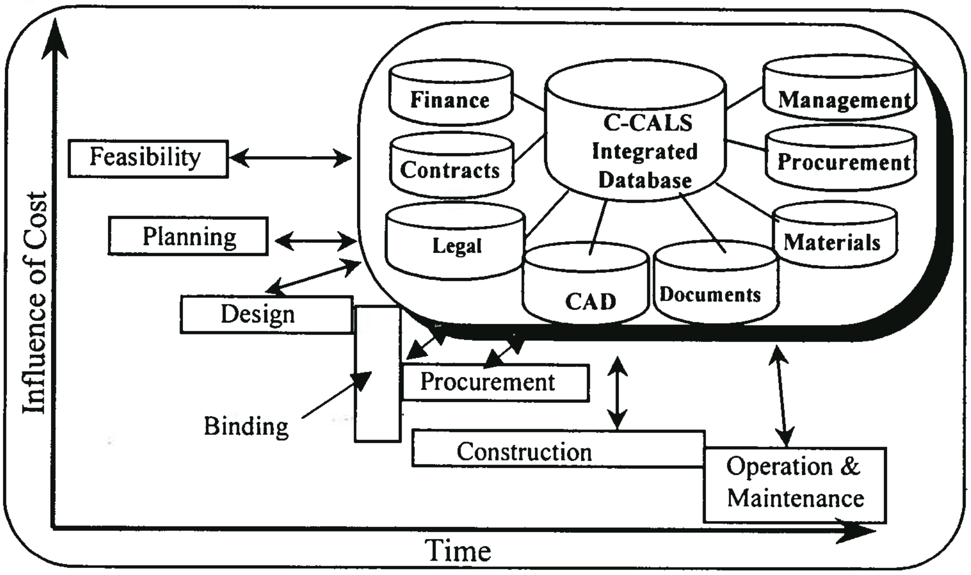

Figure 1: Application of C-CALS strategy to construction projects

Three important issues have to be addressed in implementing C-CALS. Namely, they are policies/strategies, standards, and information techniques. Governmental agencies and industry representatives are more concerned with the issues of policies and strategies. The former have to set up related strategies in order to encourage the activities at the national level, while the latter are more interested in how to adopt the CALS concept and then make more profits in executing CALS. Standards for information exchange are crucial to the success of C-CALS. They have to do with the characteristics of products along their life cycle. However, the standards in CALS are more concerned with the ones that can be uniformly applied to every industry needed in the process of producing and operating products. In addition, CALS utilizes advanced information techniques to make technical documents flow through computer networks for the purpose of engineering, manufacturing, and maintaining products along their life cycle. The technical documents may include such information as design criteria, engineering drawings, and technical specifications. The environment needed by C-CALS contains integrated databases, information infrastructure (computers and networks), and software tools for information processing.

3 DATA NORMALIZATION

A construction project generally goes through the business, planning, design, detailed design, procurement, construction, operation, and maintenance phases. Therefore, the computer system of each phase might be different from one phase to another. Traditionally, engineers consider only how to complete their jobs, without the needs of thinking how their downstream phases can utilize their output engineering information efficiently and effectively. Furthermore, even within the same phase, participants may have different technical backgrounds. Therefore, during the information transfer or data processing from one phase to another, or from one task to another, information might be lost or need to be reworked. The critical reasons for this problem to occur can be attributed to the following two major factors: no data sharing and no standardization between tasks and/or phases. This problem can be solved by using C-CALS strategy to establish an integrated database shared by all participants through the project life cycle.

To implement a C-CALS strategy, this paper proposes a data normalization model by making use of the concept of information flow network, data sharing, and data standardization. The information exchange and transfer among the participants along a construction project life cycle can be simulated as an information flow network, in which each node represents a task that needs input information from its upstream tasks and then provides output information for its downstream tasks. All the tasks in the network comprise a process for the project delivery. As shown in Figure 2, this paper identifies six critical cases to implement this C-CALS-based database by employing data sharing and data standardization within the information flow network. Six information flow networks for the six cases are shown in Figures 3 to 8, respectively. The major features of these six cases of data normalization are listed in Table 2.

It is important for us to estimate costs and benefit of each case in order to make a better decision of re-engineering a company's information processing. Though, it is difficult enough to make conceptual cost estimates in construction, where the technology advances slowly and the products are still mostly tangible. It is highly significant for us to make a right decision to implement a suitable case that can best solve the enterprise's problem. Otherwise, any misleading decision from a rough judgement will cost more than an unsuitable decision. Hence, this paper presents a cost comparison analysis to help us select the best decision among the six cases of data normalization process.

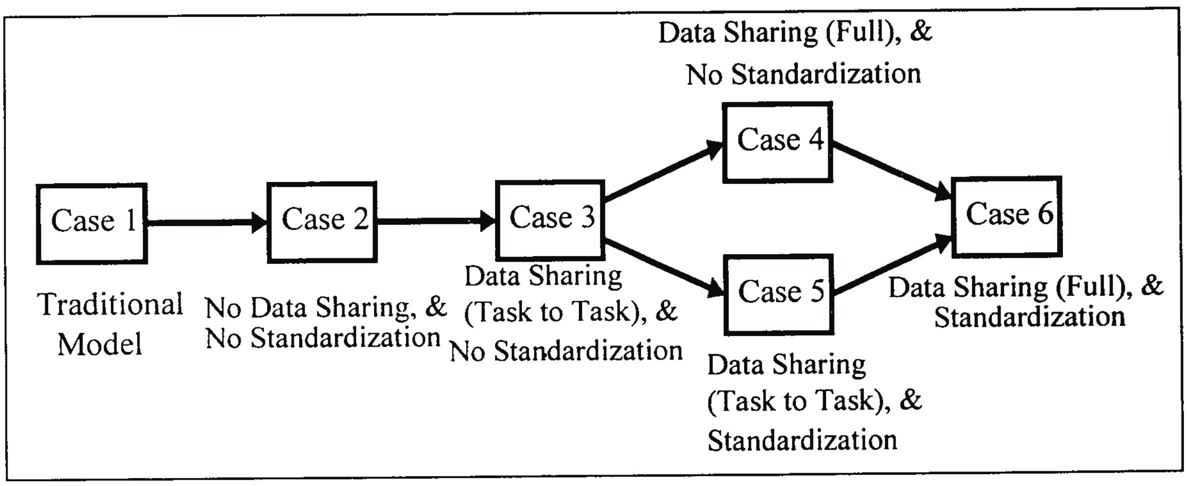

Figure 2: Cases of Developing Data Sharing System and Data Standardization

Table 2: Cases of Data Normalization

Data Normalization	Data Sharing		Data Standardization	Task Input	Task Output
	Task to task	Centralized			
Case 1	No	No	No	1	1
Case 2	No	No	No	M	N
Case 3	Yes	No	No	M	N
Case 4	Yes	Yes	No	M	N
Case 5	Yes	No	Yes	M	N
Case 6	Yes	Yes	Yes	M	N

Note: M and N in last two columns stands for multiple data flows of input or output data.

Case 1 represents the simplest case in which the process is formed by a series of tasks, each requiring a single database for input data and another database for output data (see Figure 3). In this case, the format, representation, interpretation of input data for each task can be different from each other. Because the input data is not standardized, every task might have to translate its input data into a proper form before it can process. If the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, and number of data translations are 2N, N+1, and N, respectively.

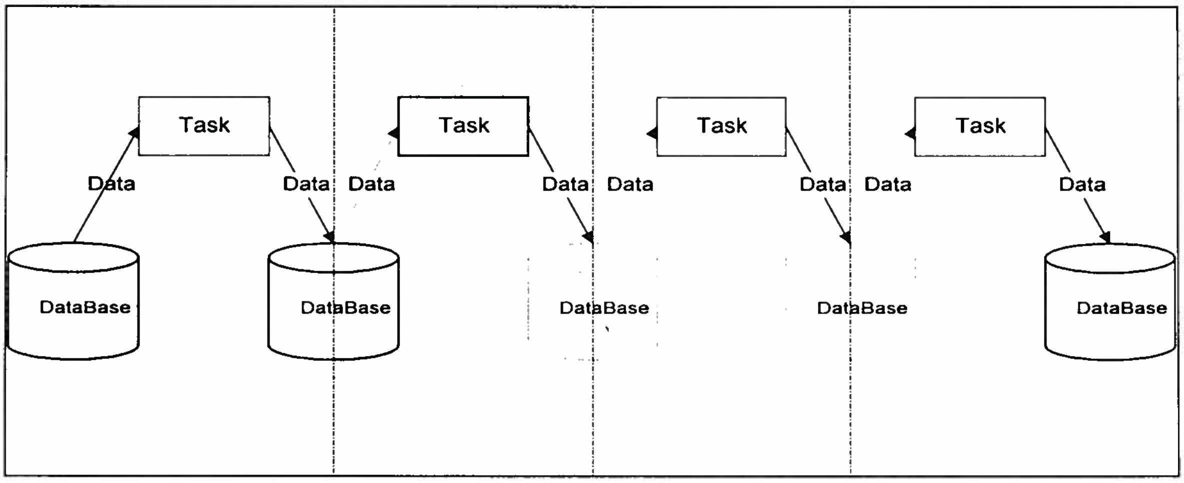

Figure 3: Information flow network of Case 1

The information flow network for the process of Case 2 is generalized from Case 1 to cover tasks that might have multiple input data sources and multiple output data sources, each being stored in a database (see Figure 4). In this case, there is no data sharing between two tasks. The data used is not standardized either. Therefore, if the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, and number of data translations are $\sum_{j=1}^{N}(NI_j + NO_j)$, $\sum_{j=1}^{N} NO_j + NI_1$, and $\sum_{j=1}^{N} NI_j$, respectively, where NI stands for number of input data sources and NO for number of output data sources.

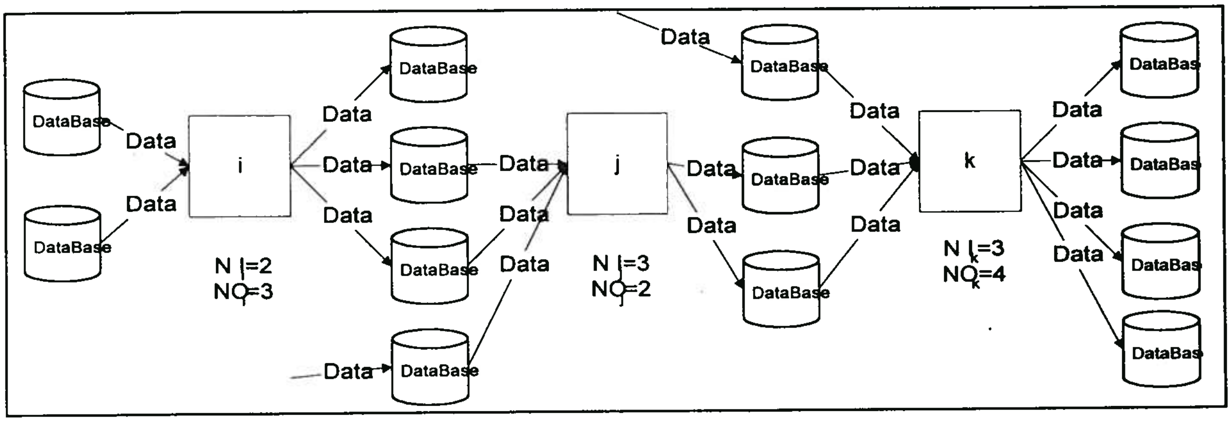

Figure 4: Information flow network of Case 2

Derived from Case 2, databases between two tasks are shared in Case 3 (see Figure 5). In this case, data is not standardized either. Therefore, if the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, and number of data translations are $\sum_{j=1}^{N}(NI_j + NO_j)$, N+1, and $\sum_{j=1}^{N} NI_j$, respectively.

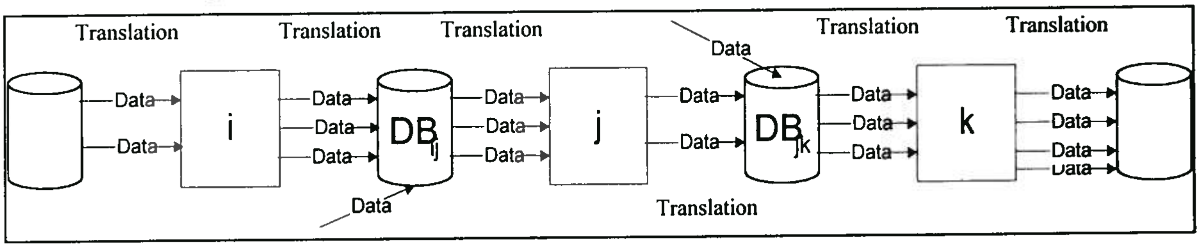

Figure 5: Information flow network of Case 3

Derived from Case 3, databases among all tasks of a process are shared in Case 4. In this case, there is a data sharing system among all tasks, but still no data standardization within this process (see Figure 6). If the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, and number of data translations are $\sum_{j=1}^{N}(NI_j + NO_j)$, 1, and $\sum_{j=1}^{N} NI_j$, respectively.

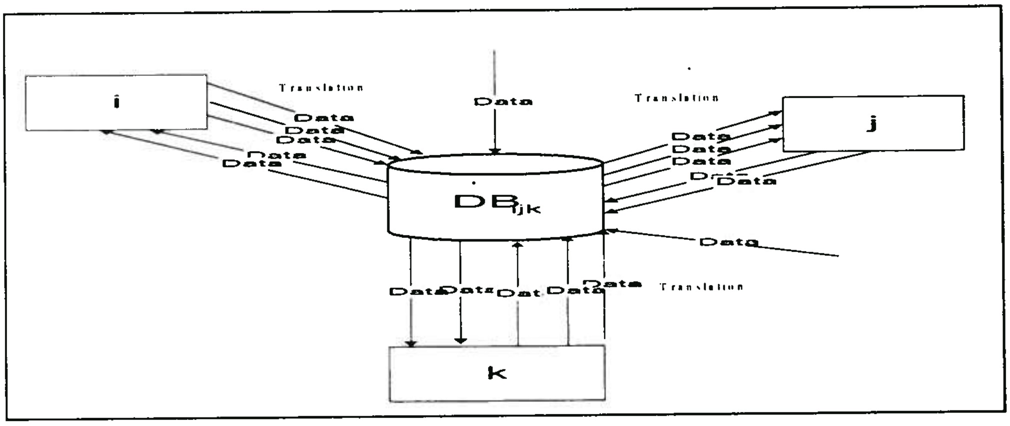

Figure 6: Information flow network of Case 4

Derived also from Case 3, the databases among two tasks are shared and the data in the process is standardized in Case 5 (see Figure 7). In this case, there is a data-sharing system for each pair of tasks. Note that no data translation is required, since the data are standardized. If the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, number of data translations, and number of data standardization are $\sum_{j=1}^{N}(NI_j + NO_j)$, N+1, 0, and 1, respectively.

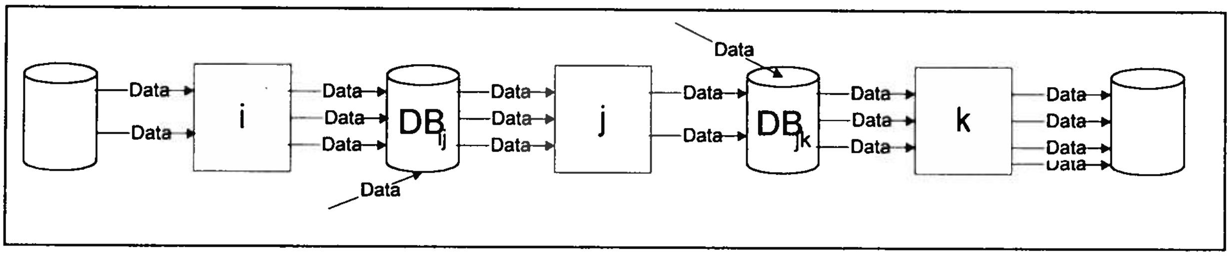

Figure 7: Information flow network of Case 5

Derived from Cases 4 and 5, the information flow network of Case 6 establishes an integrated database to offer the features of data sharing and data standardization in a process (see Figure 8). If the number of tasks in the process is N, then the number of data transfer between two tasks, number of databases, number of data translations, and number of data standardization are $\sum_{j=1}^{N}(NI_j + NO_j)$, 1, 0, and 1, respectively. The features of the six Cases are summarized in Table 3.

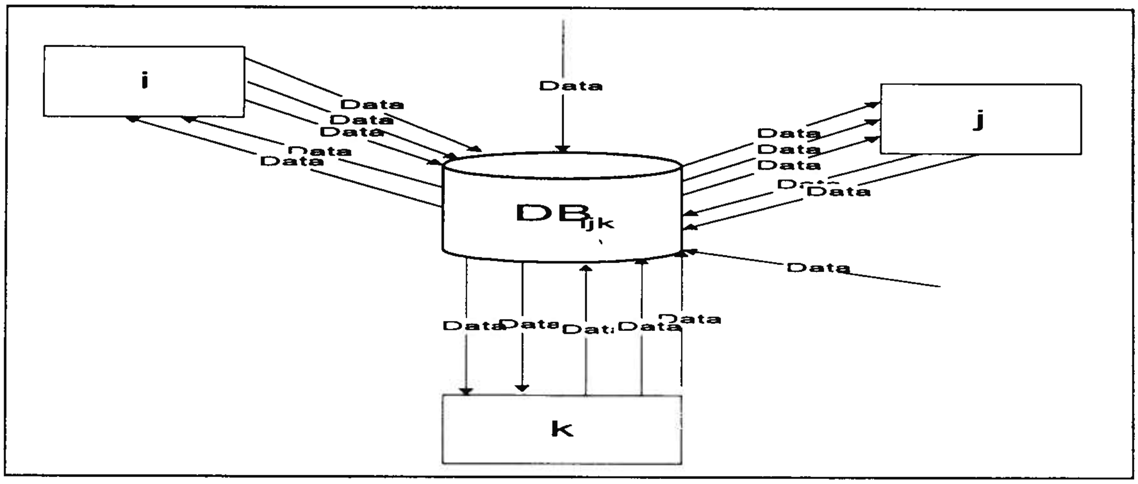

Figure 8: Information flow network of Case 6-Data sharing and data standardization

4 COST-BENEFIT ANALYSIS OF C-CALS

To measure which Case is appropriate in the possible data normalization model, this paper proposes a cost model to calculate the investment cost for each Case. If we also consider the possibility of data reuse of repeated processes, then the investment cost for each can be generated by the following equation:

Investment Cost = (Cost of Data Transfer + Cost of Database Maintenance + Cost of Data

Translation) * No. of Processes + Cost of Data Standardization (1)

The benefits of each Case are depended on the time, cost, and errors during data processing. As we can see in Table 3, numbers of data translations in Case 5 and 6 are zero that will reduce the time, cost, and errors. However, the detailed benefit analysis will not be described in this paper currently.

Table 3: Summarized Features of Implementing Integrated Database

Case	No of Tasks	No of Data Transfer	No of Database	No of Data Translation	No of Data Standardization
1	N	2 N	N + 1	N	0
2	N	$\sum_{j=1}^{N}(NI_j + NO_j)$	$\sum_{j=1}^{N} NO_j + NI_1$	$\sum_{j=1}^{N} NI_j$	0
3	N	$\sum_{j=1}^{N}(NI_j + NO_j)$	N + 1	$\sum_{j=1}^{N} NI_j$	0
4	N	$\sum_{j=1}^{N}(NI_j + NO_j)$	1	$\sum_{j=1}^{N} NI_j$	0
5	N	$\sum_{j=1}^{N}(NI_j + NO_j)$	N + 1	0	1
6	N	$\sum_{j=1}^{N}(NI_j + NO_j)$	1	0	1

Note: NI and NO stand for number of input data sources and output data sources, respectively.

5 EXAMPLE

Based on the cost model described above, the following example will illustrate the investment cost of each Case. Assume we have a process consisting of 3 tasks, say A, B, and C, with the information flow network of Case 2 as shown in Figure 4. The numbers of input and output data sources for these three tasks are listed in Table 4. Based on Table 3, we can derive the data normalization features for the example, as listed in Table 5.

Table 4: Data Sources of Example

Task	No of Input Data Sources	No of Output Data Sources
A	2	3
B	3	2
C	3	4

In analysis I, we assume that the data transfer cost, database maintenance cost, data translation cost, data standardization cost, and number of processes (reuse) are 1, 20, 100, 2000, 100, respectively. After calculating Equation 1 for each case, the results are shown in Table 6. The investment costs for Case 2 and 6 are 103700 and 5700, respectively. This means that the cost-benefit ratio for data normalization is 18 times. If we perform some sensitivity analysis by changing the number of unit costs or processes, we can have different results, as in analysis II or III.

Table 5: Summarized Features of Example

Example	No of Transfer	No of Database	No of Translations	No of Standardizations
2	17	11	8	0
3	17	4	8	0
4	17	1	8	0
5	17	4	0	1
6	17	1	0	1

Table 6: Results of Cost Estimating for Each Case

Case	No of Data Transfer	No of Database	No of Data Translation	No of Data Standardization	Analysis I	Analysis II	Analysis III
2	17	11	8	0	103700	103700	311100
3	17	4	8	0	89700	89700	269100
4	17	1	8	0	83700	83700	251100
5	17	4	0	1	11700	12700	31100
6	17	1	0	1	5700	6700	13100
				Ratio (Max/Min)	18.2	15.5	23.7
				Data Transfer Unit Cost	1	1	1
				Database Mainten. Unit Cost	20	20	20
				Data Translation Unit Cost	100	100	100
				Standardization Unit Cost	2000	3000	2000
				No of Processes (Reuse)	100	100	300

6 CONCLUSIONS

To continuously improve construction project productivity and quality along the life cycle, C-CALS can be implemented by integrating exchange standards and processing tools for engineering information. C-CALS is expected to provide paperless environments so that project time can be shortened, cost reduced, as well as quality and productivity improved. In order to survive and prosper, all parties in the construction industry might need to understand CALS strategies, standards, and technologies. This paper identifies six different cases to for a construction company to build a CALS-like system. Furthermore, a detailed cost-benefit estimating of each case has been developed to guide the company to implement an efficient and economic CALS-like system.

7 REFERENCES

[1] Elwood, George P., "What is CALS all about?" Proceedings of the IEEE Systems Readiness Technology Conference, Sep. 20-23, San Antonio, (1993), pp. 497-500.

[2] Brooks, G., "Changes in the Documentation Engineering Process," Electrical Communication Second Quarter, Paris, (1994), pp. 173-180.

[3] Lally, Peter C., "CALS - A Mighty Step Forward," Professional Engineering, Vol. 6, No 4, (1993) April, pp34-35.

[4] Wang, Ming-Teh, "Development of Construction CALS," ASCE, *Construction Congress V*, Minneapolis, MN, (1997) Oct. 5-8, pp.1046-1055.